Late Holocene Environmental Changes On Kurnell Peninsula, NSW

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Studies of stratigraphy, mineral magnetic characteristics, organic matter, selected cation, pollen and charcoal abundances were used to reconstruct environmental changes from three perched swamps on Kurnell Peninsula, NSW (151°13′E, 34°02′S).

Swamp sediments began accumulating between 2400 and 1680 years ago. Organic matter collected in these depressions continuously as vegetation communities developed on the newly formed Holocene dunes. Periods of mineral sediment supply from eroding catchments and oceanic influx punctuated this organic build-up. An increase in charcoal input into the sediments was noted for the period 1040-200 years Before Present, most probably due to Aboriginal burning. This was accompanied by an increase in the abundance of sclerophyllous vegetation species. Since European settlement, increasing catchment erosion, increased turbidity of swamp waters, an altered fire regime, and a greater supply of magnetic aerosols have occurred.

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INTRODUCTION

The fundamental method of identifying past physical changes from swamp profiles is stratigraphic — aided by sedimentological, petrographic, palaeontological, geomorphic and geochemical studies (Chappell, 1978). Therefore, a multi-disciplinary approach to the analysis of environmental change is desirable for quantifying past changes. This study draws on a number of techniques to reconstruct a history of environmental conditions on Kurnell Peninsula during the last 2400 years.

STUDY AREA

Kurnell Peninsula forms the southern shore of Botany Bay, about 12 km south of Sydney (Fig. 1). It is a unique cultural resource because of its historical significance, its importance for recreational and scientific purposes, its value as a source of extractive materials and the site for many manufacturing industries.

The current climate of the study area is temperate coastal. However, due to the rugged topography of the Kurnell Headland, and its coastal location, many micro-climates result. The region experiences warm to hot summers and mild winters. Average annual rainfall is 1100 mm, most of which falls in the period January to June. Rainfall occurs approximately 130 days per year. Prevailing winds are from the south east during summer and autumn, and the west during winter (Bureau of Meteorology).

During the Early Holocene, when sea level rose to between 9 and 20 m below its present level, marine sands were reworked from the Pleistocene marine substrata and washed into the near-shore zone to form spits and beach ridges. Tidal deltaic deposits issued from the Georges River and Port Hacking Estuary. These sediments and those supplied by littoral drift from further south were deposited between Port Hacking Point and Kurnell Headland (island) to form a proto-barrier. This material was to be later reworked across Bate Bay to form the present day Kurnell Isthmus. Activity had probably ceased by the Late Holocene (Roy and Crawford, 1979; Hann, 1986).

Urwin (1980) described five land units for the study area (Fig. 1). The Bedrock

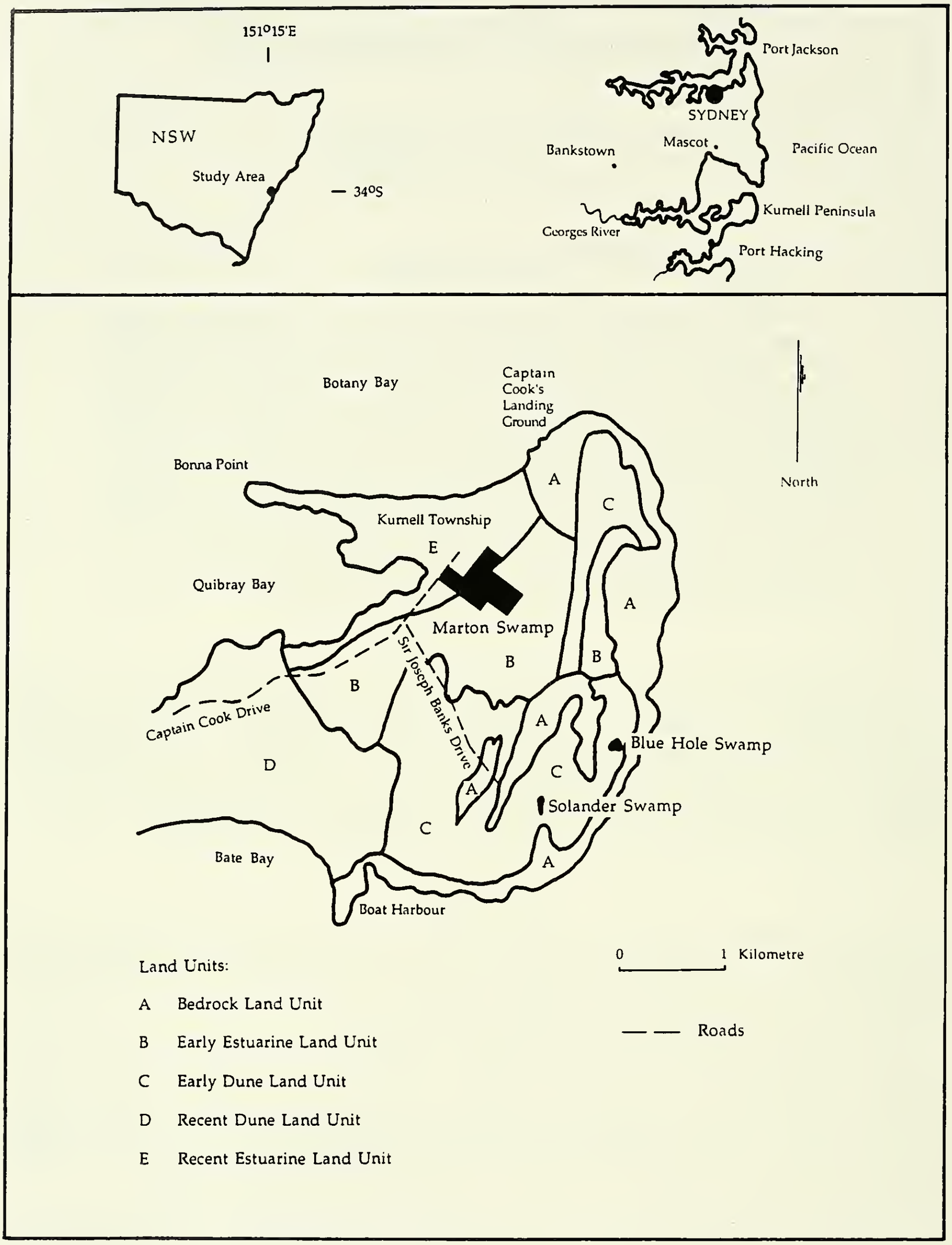

Fig. 1. Location maps and Land Units.

Land Unit of Hawkesbury Sandstone is the oldest. It occurs along the eastern edge of the Peninsula. Some areas are covered by shallow sandy soils. Other areas have deeper podzols, aeolian sands derived from the proto-barrier. The underlying sandstone is impermeable, except where subject to joint fracturing, so a high water table is maintained in these Holocene sands. Thus, swamps on the Peninsula form as windows to this water table. The vegetation here comprises heathlands to the south grading to a low forest in the north. Major communities include heath (dominant canopy species of such communities include *Allocasuarina distyla*, *Banksia serrata*, *Westringia fructicosa*, *Acacia* spp., *Kunzea ambigua*, *Banksia ericifolia*); swampland (*Gahnia sieberana*, *Schoenoplectus litoralis*, *Restio* spp.); forest (*Eucalyptus gummifera*, *Angophora costata*); and woodland (*Eucalyptus* and *Angophora* spp.). The Early Estuarine Land Unit is derived from aeolian sands blown from sand bars at the ancient mouth of the Georges River. They form dunes running east-west over the bedrock unit. Soils here are deep, strongly leached, and poorly structured. The unit supports scrub (*Eucalyptus gummifera*, *Angophora costata*, *Banksia ericifolia*, *Callistemon citrinus*, *Persoonia lanceolata*, *Melaleuca ericifolia*, *Acacia longifolia* var. *sophorae*); swampland (*Juncus* spp., *Schoenoplectus* sp., *Cyperus* sp.); forest (*Casuarina glauca*, *B. integrifolia*); woodland (*Casuarina glauca*, *B. integrifolia*); and shrubland (*E. botryoides*, *B. integrifolia*). The Early Dune Land Unit sparingly overlies the above two units to form a geomorphic mosaic. It is derived from the deposition of marine sands from Bate Bay. These dunes are aligned north-south, are relatively deep and strongly podzolised, high in organic material and low in calcium. Vegetation communities include heath (*Allocasuarina distyla*, *Banksia* spp., *Leptospermum laevigatum*); scrub (*L. laevigatum*, *Banksia* spp., *Allocasuarina distyla*, *Angophora costata*, *Acacia longifolia* var. *sophorae*, *Cupaniopsis anacardioides*); woodland (*B. integrifolia*, *L. laevigatum*); shrubland (*E. botryoides*, *B. integrifolia*); grassland (*Themeda australis*); and swampland (*Gahnia*, *Schoenoplectus* spp.). The Recent Dune Land Unit comprises calcareous and unleached dunes aligned east-west. Much of this unit is unstable resulting in blowouts which have covered older stabilised dunes. This unit supports forest (*Banksia integrifolia*, *Leptospermum laevigatum*, *Allocasuarina* spp., *Cupaniopsis anacardioides*); scrub/heath (*Acacia longifolia* var. *sophorae*, the exotic *Lantana camara*); herbfield (*Spinifex hirsutus*, *Scaevola calendulacea*, the exotic *Hydrocotyle bonariensis*); and saltmarsh (*Juncus kraussii*). Parts of the Recent Estuarine Land Unit may parallel the development of the previous three units. The unit comprises mudflats, sedgelands and intertidal mangrove stands. Swampland and mangrove soils found here are a collection of organic matter and silt and have a high organic clay content (Walker, 1960). This unit supports scrub and low forest (*Avicennia marina*, *Casuarina glauca*, *Banksia integrifolia*, *Leptospermum laevigatum*, *Cupaniopsis anacardioides*); shrubland (*Aegiceras corniculatum*, *M. ericifolia*); woodland (*Eucalyptus botryoides*, *B. integrifolia*, *L. laevigatum*); saltmarsh (*Sarcocornia quinqueflora*); sedgeland/grassland (*Juncus* spp./*Phragmites australis*); herbfield (*Spinifex hirsutus*).

The soils of each land unit have a low nutrient status and water retention capacity. They are friable with a high potential for wind and water erosion, especially if the vegetation cover is removed.

Aboriginal people were known to inhabit the shores of Botany Bay along with much of the south eastern coastline of New South Wales (Megaw, 1965; Megaw and Wright, 1966; Flood, 1983). Possibly the best indication of Aboriginal numbers in the region is from Captain Cook's accounts. Each excursion made inland by the British explorers encountered natives or their huts, canoes, cooking fires, food collections, scarred trees and so on. The largest group of people seen was 20, and no settlements were found that indicated there were larger groups (Reed, 1969).

Study Sites

The names assigned to the three swamps studied have recently been gazetted by the Department of Lands following an application by the author. The locations of the swamps are shown in Figure 1.

Blue Hole Swamp is a relatively large, shallow swamp on the east coast of the Peninsula. It has an elevation of about 30 m a.s.l., and a catchment of approximately 3 ha with slope angles ranging between 8° and 14°. It is located within the Early Dune Land Unit. The material forming its base is Hawkesbury Sandstone overlain by a 5-7 m veneer of Late Holocene transgressive dune material. Its waters are about 1 m deep. Solander Swamp, also located within the Early Dune Land Unit, has an elevation of about 25 m a.s.l.. Its 6 ha catchment has slope angles ranging between 9° and 12°. The swamp is formed on a 20 m thick lens of Holocene sand. Its waters are also about 1 m deep. Between 1970 and 1985 a large transgressive dune began to invade its waters, but it is now stable. Immediately adjacent to the coring sites *Gahnia* and *Schoenoplectus* spp. dominate at both sites. The shores support shrubs and herbs such as *Callistemon* spp., *Sprengelia incarnata*, and *Banksia* spp. The surrounding heath is dominated by *Leptospermum* spp., *Acacia* spp., and *Banksia* spp. Marton Swamp is the largest inland water body in the study area located in the Recent Estuarine Land Unit. It once formed part of a tidal mud flat unit, probably colonised by mangroves and saltmarsh vegetation communities. The construction of the adjacent oil refineries and Captain Cook Drive closed it off from the sea in the early 1950's to produce the lake. Its catchment has an area of 204 ha, with slope angles between 0.5° and 3°. Its basal sediments began accumulating before 9000 B.P. (Roy and Crawford, 1979). Its waters were up to 2 m deep at the time of sampling and sparsely vegetated by *Phragmites australis*, *Typha orientalis*, *Schoenoplectus*, *Cyperus*, *Juncus* and *Gahnia* spp. The surrounding area is dominated by *Casuarina glauca*, *Melaleuca ericifolia* and *Cotula coronopifolia*.

The swamps at Kurnell are of low biological activity (Johnson, 1981) and hence do not experience bioturbation. Aquatic plant roots are restricted to the upper 5 cm of sediment in the swamps.

METHODS

The following attributes of the swamp sediments were analysed: mineral magnetism, stratigraphy; organic matter content; total phosphorus, sodium, potassium, magnesium, calcium, iron, and aluminium ion concentrations; and pollen and charcoal distributions. Selected materials were also dated by radiocarbon techniques to provide a time sequence.

Sediment was collected with a Russian sampler (Jowsey, 1966). Vertical, duplicate samples were extracted from each of the three swamps. In each case cores were taken from the middle of the swamp to minimise the risk of disturbance. The corer was pushed until it was stopped by impenetrable basal sand. The stratigraphy of each core was described using the Troels-Smith method as outlined in Birks and Birks (1980).

Each core was passed through a Bartington Magnetic Susceptibility Loop, at contiguous 2 cm intervals to measure variation in magnetic susceptibility (core loop magnetic susceptibility, or CLMS). Single sample magnetic susceptibility (SSMS) was also determined.

Sub-samples were oven dried at 40°C and transferred to a muffle furnace at 550°C for 20 minutes to determine their percentage loss on ignition (PLOI). Variations in cation concentrations were measured on the ash from the PLOI procedure. This was prepared by a hydrochloric acid digest as described by Murphy and Riley (1962). Clymo (1983) suggested that most hydrogen, sodium, potassium, magnesium and calcium in ombrogenous peat are exchangeable and these ions may be successfully extracted by concentrated acid. Thus, the majority of ions incorporated into the organic matter could be expected to be brought into solution. The supernatant from the acid digest solutions was analysed on a Pye Unicam SP9 Atomic Absorption Spectrophotometer.

An aliquot of this solution was prepared for determination of total phosphorus as outlined by Esdaile and Colwell (1963) using a Bausch and Lomb Spectrometer.

Pollen samples were prepared using the standard alkali, acetolysis, and dehydration procedure outlined in Faegri and Iverson (1975) and Moore and Webb (1978). However, the cold hydrofluoric acid (50%) treatment was replaced with a zinc bromide treatment to remove any heavy mineral fraction from samples (modified from Clark, 1984). Samples were measured volumetrically and spiked with an *Alnus rugosa* 'pill' containing 151,000 +/- 9,060 pollen grains to help estimate pollen concentrations. Prepared residues were counted for the following pollen taxa: *Eucalyptus*, *Leptospermum/Baeckea*, *Pteridium*, Poaceae, Casuarinaceae, *Banksia*, *Acacia*, *Haloragis (Gonocarpus)*, *Gleichenia*, *Monotoca*, Lobeliaceae and Restionaceae. These taxa were chosen after consideration of those found to be most meaningful in other environmental change studies in the Sydney region (Chalson, 1983; Kodela, 1984). In addition, *Plantago lanceolata* and *Pinus* (two introduced taxa) were counted to locate the level at which European people began to affect the environment. The 'point count' method (Clark, 1982) was used to estimate microscopic charcoal concentrations. Data for the longest core only (that being Marton Swamp) was collected.

In analysing the changes in the chemical data (against depth) by way of statistical procedures, a major restriction is that imposed by 'positive spatial autocorrelation'. That is, individual observations tend to be positively correlated with adjacent observations in an ordered (time) series. The absence of autocorrelation in data is an assumption for all linear regression techniques (Norcliffe, 1977). Therefore a statistical test was employed to analyse the data that would not look at individual observations but groups of observations. The median test is a measure of central tendancy of ordinal scale data and compares the magnitude of the middle value of groups of ranked data. For this analysis the analytical data from each swamp was subjectively split into groups having relatively uniform characteristics or phases of change between stable levels. The groups chosen were:

Blue Hole Swamp	–	16-11, 11-9, 9-3, 3-0 cm
Solander Swamp	–	51-32, 32-10, and 10-0 cm
Marton Swamp	–	43-20, 20-11, and 11-0 cm.

To observe the possible interactions between taxa and charcoal over time, a time series analysis package developed for use with pollen data was employed (POLSTA, Green, 1983).

Results and Discussion

The core stratigraphies for the three swamps are related to each other in Figure 2. Blue Hole Swamp contains fine sand particles at 13-16 cm that are probably from the Holocene basal material. Inorganic sediment supply to the swamp from the catchment is very low. This is in keeping with the small size and gentle slopes of the catchment. The lack of stratigraphic boundaries suggests that deposition of plant material occurred with no significant breaks. Accumulation of organic matter began around 1680 B.P. +/- 70 (Laboratory Number: Beta-21346) at Solander Swamp and continued until c. 1300 B.P.. From 37 cm to 25 cm small quantities of sand were supplied to the swamp. Thereafter, organic matter accumulation continued until the Present. The recent invasion of the swamp by the transgressive dune is not recorded in the sediments sampled. The dates recorded here would seem applicable to the Blue Hole chronology as they are located in the same land unit. The lowest sand layer in Marton Swamp (below 53 cm) is presumably the Holocene spit sediment that forms the swamp's base. Material directly above this was dated at 2410 +/- 270 (Laboratory Number: Beta-21345). Sand deposited between 43-45 cm indicates a well-defined period of mineral influx. Due to the very gentle slope and high infiltration rates of the surrounding terrestrial landmass, this influx is probably of marine origin, and corresponds with a period of estuarine reworking and resultant deposition of this unit during the Late Holocene (see Roy and Crawford, 1979). Organic matter supply increased markedly after 1040 B.P. +/- 90 (Laboratory Number: Beta-21344) to peak around 11 cm. Shells found in the depth range 0-12 cm in the Marton core were of the snail *Hydrobia victoria* (Jerrard Clark, Australian Museum, pers. comm.). In Mr. Clark's opinion the shells were fossil shells, as the snail is a non-burrowing species. The possibility that these shells were washed in may be discounted as no other inorganic material of similar size was found in this layer. The snails may be killed by water containing high amounts of suspended sediment. This could be achieved by increased turbidity of the swamp water due to human activity. In fact, graphing the radiocarbon dates against depth illustrates sediment influx rates for Marton Swamp have increased 8-fold since European settlement.

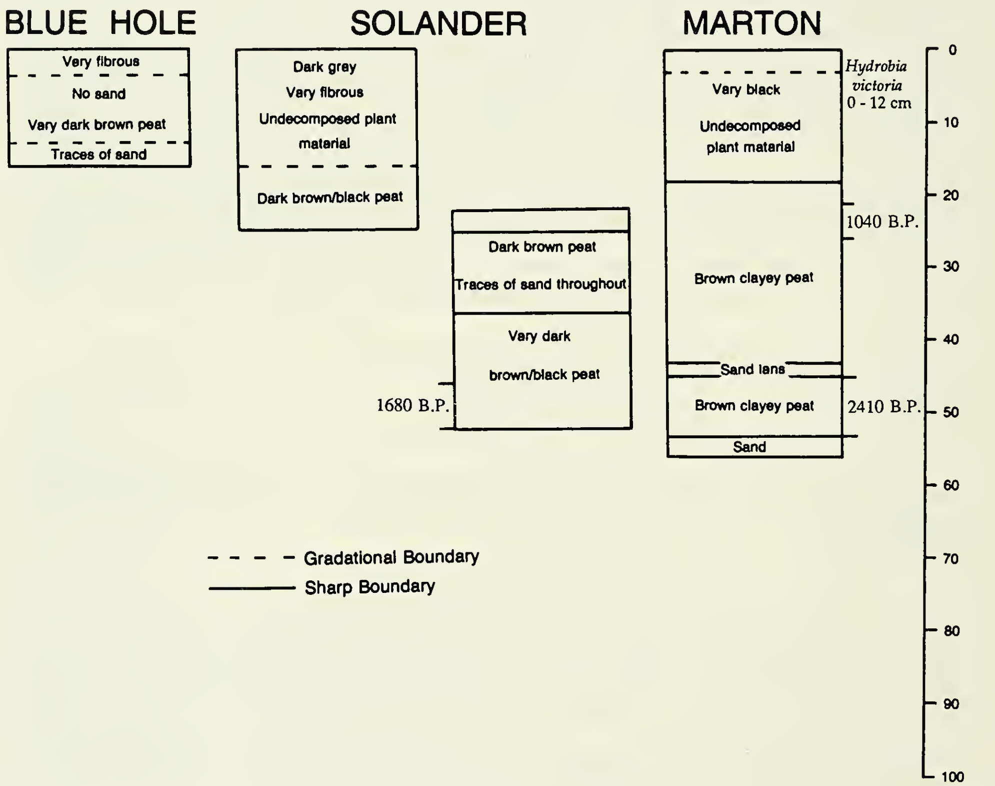

Fig. 2. Stratigraphies of cores from each swamp sampled.

All PLOI, magnetic susceptibility and geochemical parameters studied changed significantly since the formation of the swamps as determined by the median test (0.05 level of significance). The PLOI data increase away from the base to obtain relatively high levels for the majority of the profile and then decrease towards the surface (Figs. 3, 4 and 5). This can be explained: accumulation of organic matter accelerated following

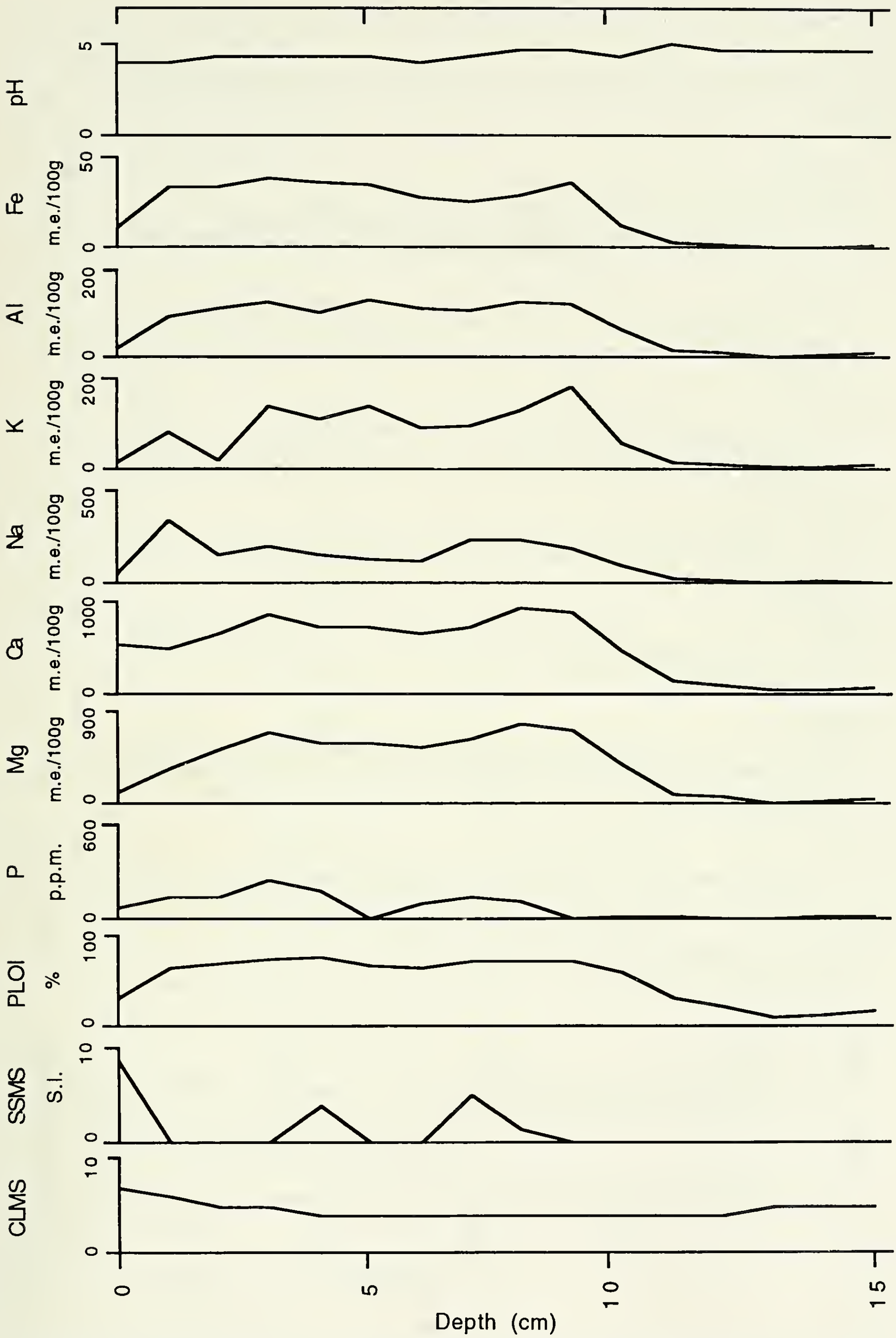

Fig. 3. Blue Hole Swamp magnetic susceptibility (Core Loop — dimensionless; Single Sample — $10^{-6}GOe^{-1}$), percentage-loss-on-ignition, elemental geochemistry (milli-equivalents/100grams) and pH.

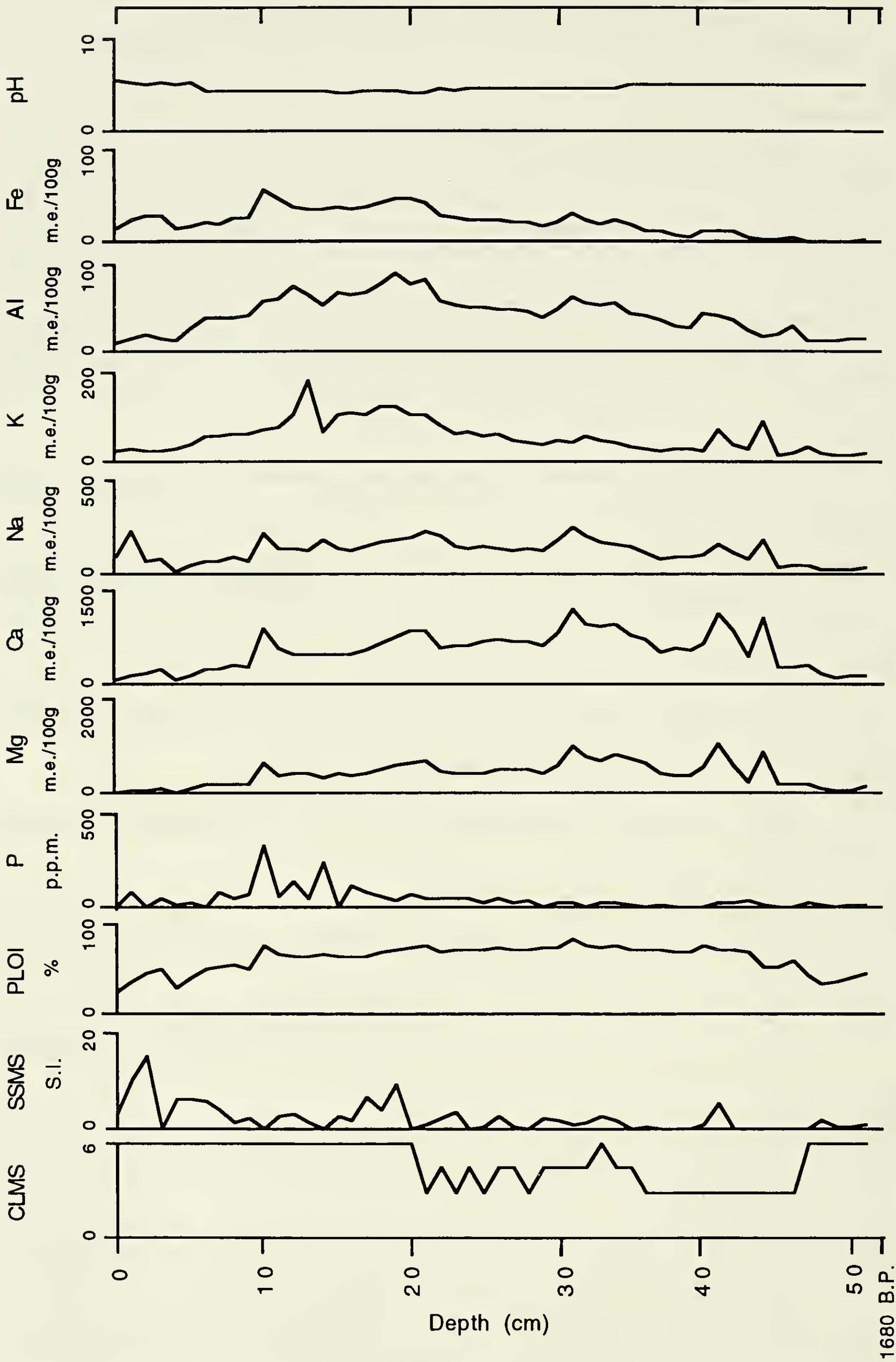

Fig. 4. Solander Swamp magnetic susceptibility (Core Loop – dimensionless; Single Sample – $10^{-6}GOe^{-1}$), percentage-loss-on-ignition, elemental geochemistry (milli-equivalents/100 grams) and pH.

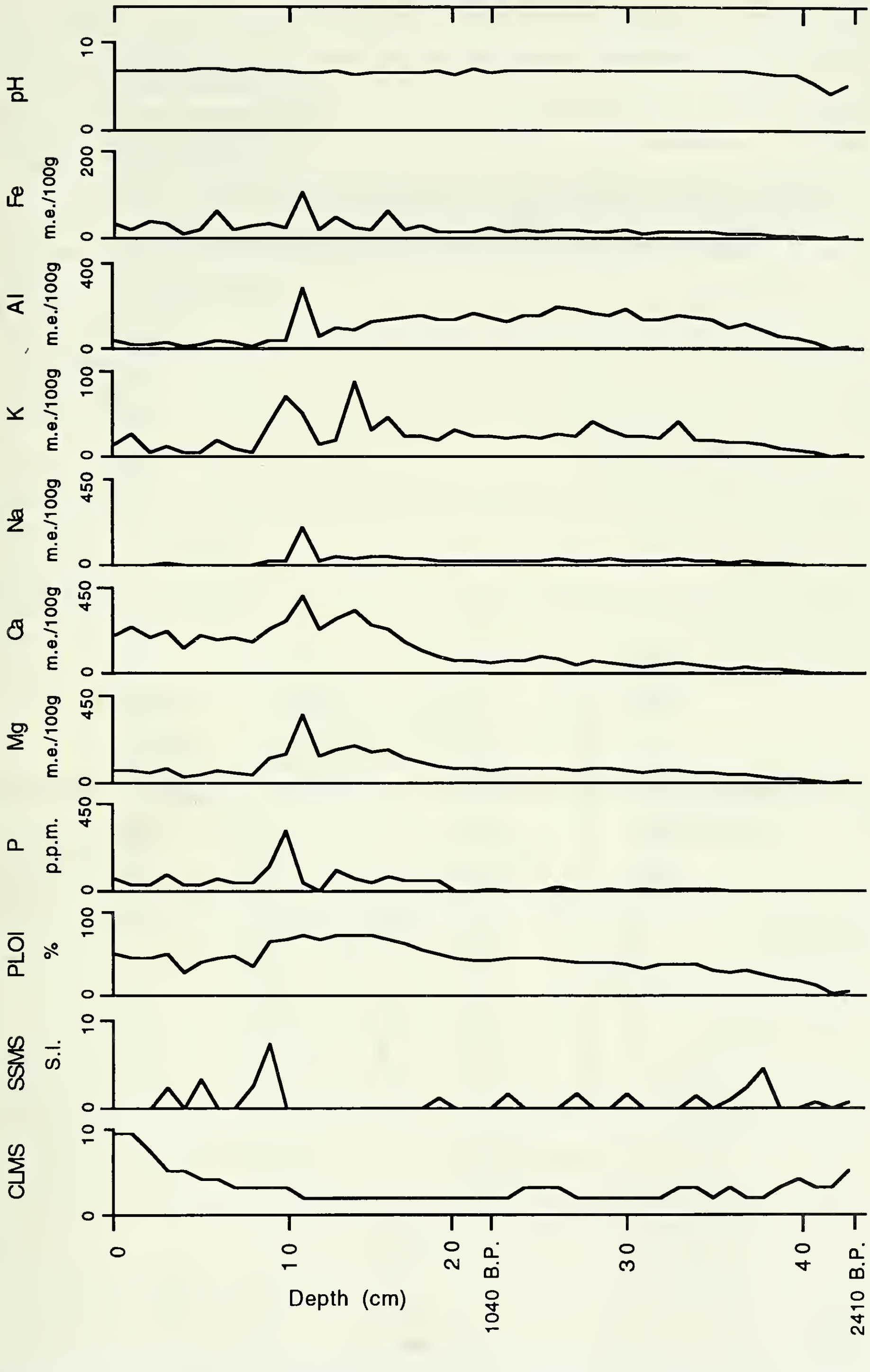

Fig. 5. Marton Swamp magnetic susceptibility (Core Loop — dimensionless; Single Sample — $10^{-6}GOe^{-1}$), percentage-loss-on-ignition, elemental geochemistry (milli-equivalents/100 grams) and pH.

the inception of the depositional basin due to vegetational succession on and around the swamp. That material closer to the surface contains an increasing percentage of water and elasticity as compared to the more decomposed and compact lower sediments. A strong positive correlation exists between the PLOI data and those for all cations suggesting that cations preserved in the peat are incorporated in the dead plant material. This confirms Clymo's 1983 statement, regarding ions incorporated into the organic matter being brought into solution, mentioned earlier. The surface layers (c. 0-5 cm) are deficient in organic matter, cations, and minerals, yet record high CLMS and SSMS readings. Low organic matter and cation levels were expected as these layers consist mainly of water, however, high CLMS and SSMS readings are not explicable from these data. This may reflect errors induced due to the sediment's high moisture content and 'feeling' of air by the scanners. However, such a phenomenon was not apparent at the other end of the core. Another possible explanation is an anthropogenic influence. That is, the addition of magnetic aerosols to the swamp by the combustion of fossil fuels or in-wash of magnetic minerals from the surrounding area (Oldfield *et al.*, 1981; Hunt *et al.*, 1984). Considering the industrial establishments located in the study area, this appears plausible.

Table 1 shows higher magnesium, calcium, sodium and potassium readings in the Solander and Blue Hole Swamp sediments than the Marton Swamp sediments. This may be related to the location of Solander and Blue Hole Swamps near the ocean and its ion-bearing breezes, or the differing basal materials that catchment waters percolated through. The Early Dune material may be a richer source of cations than the Recent Estuarine sands. Urwin (1980) suggests that this area of the Early Dune Land Unit is unleached and calcareous.

TABLE 1
Mean parameter levels between swamps

Parameter	Blue Hole Swamp	Solander Swamp	Marton Swamp
C.L.M.S.	4.6	5.6	3.1
S.S.M.S. ($10^{-6}GOe^{-1}$)	1.2	2.2	0.7
P.L.O.I. (%)	51.6	62.4	42.7
P (me/100g)	56.7	38.1	32.4
Mg (me/100g)	448.0	474.9	80.5
Ca (me/100g)	502.8	766.0	132.0
Na (me/100g)	124.7	127.7	30.9
K (me/100g)	72.1	60.6	23.3
Al (me/100g)	74.6	43.6	125.4
Fe (me/100g)	20.6	24.6	28.4
pH	4.5	5.0	6.8

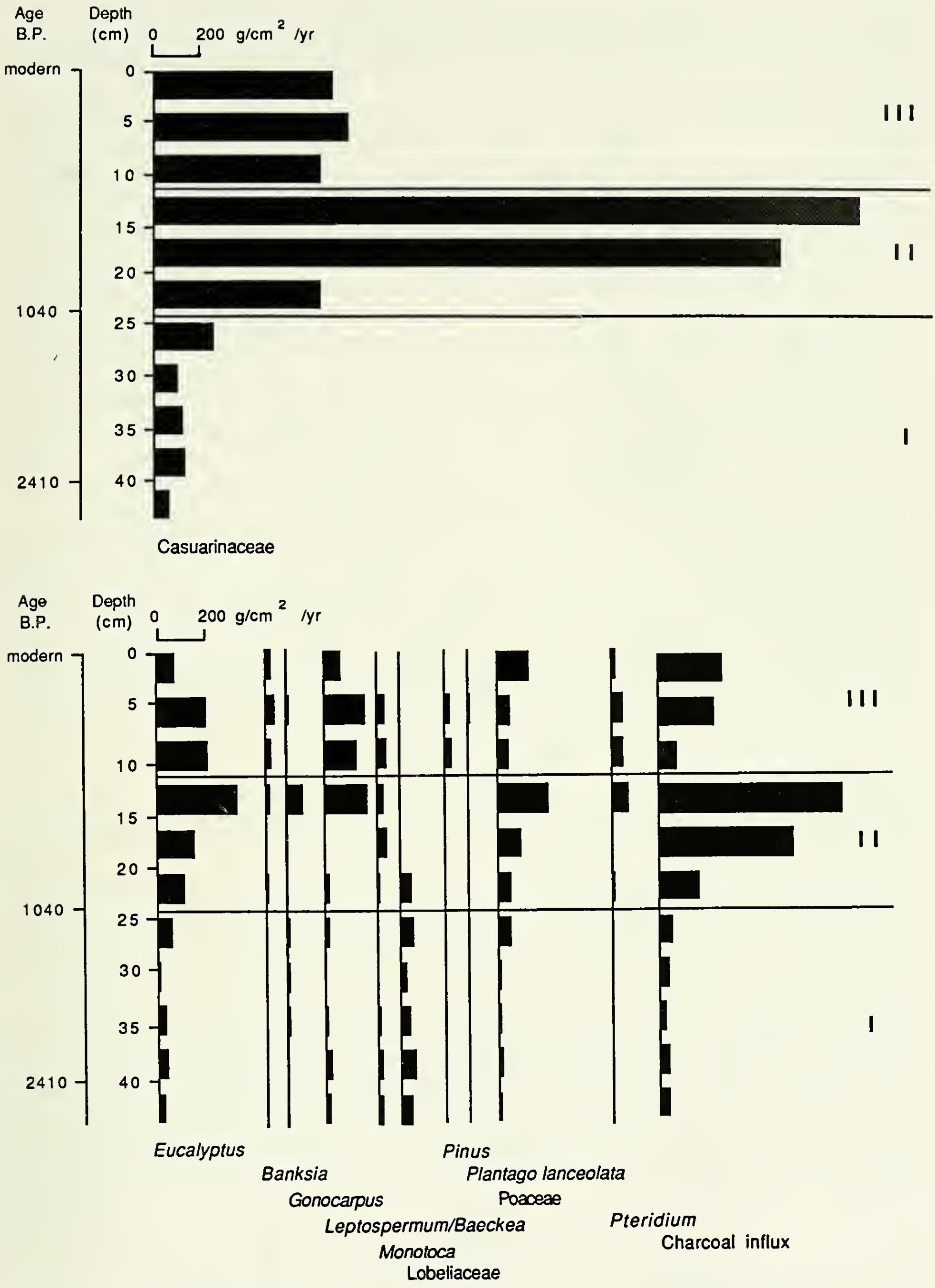

Fig. 6. Pollen influx for Marton Swamp.

The pollen data for Marton Swamp (Fig. 6) indicate a relatively stable vegetative community during Zone I (Zones were determined by the ZONATION computing package). After 1040 B.P. (Zone II), Lobeliaceae disappears from the record.

TABLE 2

Correlations between taxa and charcoal as determined by Polsta

	Allocasuarina	*Banksia*	*Eucalyptus*	*Haloragis*	*Leptospermum/Baeckia*	*Monotoca*	Lobeliaceae	*Pinus*	*Plantago lanceolata*	Poaceae	*Pteridium*	Charcoal
Allocasuarina	1											
Banksia	-2	1										
Eucalyptus	+0	+2	1									
Haloragis	+0	+2	+0	1								
Leptospermum/Baeckia	-1	+0	+0	+0	1							
Monotoca	-2	+1	-1	+/-1	+1	1						
Lobeliaceae	-1*	+1*	-0*	+1*	+1*	-0*	1					
Pinus	-2	+1	-1	-1	-1	+0	-1*	1				
Plantago lanceolata	-2	+0	-2	-2	-2	-1	-3*	-1	1			
Poaceae	+0	+2	+0	+0	+2	+1	-0*	+1	+2	1		
Pteridium	-1	+0	+0	+0	+0	-1	-1*	+1	+2	+0	1	
Charcoal	+0	+2	+0	+0	+2	+2	-0*	+2	+2	+0	+1	1

Key:

* Negative Correlation
\+ Positive Lag
\- Negative Lag
Number Indicates Number of time lag periods.

Casuarinaceae, *Eucalyptus*, *Leptospermum/Baeckea*, *Monotoca*, Poaceae, and to a lesser extent, *Pteridium* and *Gonocarpus*, increase in abundance until 150 B.P.. All taxa decrease in abundance toward present times (Zone III). The charcoal record reveals a similar pattern to the group of plant taxa described above. Aboriginal burning practices are most probably responsible for the increasing charcoal input during Zone II. It seems reasonable to relate the vegetative changes at this time with an increased Aboriginal burning regime as inferred by the microscopic charcoal record. After an initial drop, charcoal increased throughout Zone III but does not reach the heights of the 13 cm levels. This sequence may relate to the changeover in the land's caretakers as Aboriginal people were driven out of the Kurnell region by European. The presence of *Pinus* and *Plantago lanceolata* pollen in the upper most samples of the Marton core helps fix the stage of European settlement as being between 10 and 13 cm. This corresponds with the stratigraphic location of *Hydrobia victoria* shells (Fig. 2) and the charcoal record scenario described above. POLSTA indicates that fire has favoured understorey/disturbance species, such as Poaceae and *Pteridium*, but also Casuarinaceae, *Eucalyptus*, *Gonocarpus*, *Leptospermum/Baeckea*, and *Monotoca* (Table 2). The fact that a grassland community does not rise to dominance over the shrubs and trees may suggest that the fire regime, even at times of apparent frequent occurrence, was not very intense.

A climatic variation may need to be considered here. Climates in south eastern Australia during the last 2 to 2000 years have been similar to that experienced today (Bowler *et al.*, 1976; Coventry and Walker, 1977; Singh *et al.*, 1981). However, numerous studies in south eastern Australia have indicated some slight fluctuations in climatic conditions during the Late Holocene. For example Kodela (1984) at Kui-ring-gai Chase National Park found that conditions may have been warmer and drier around 1700 B.P.. Unfortunately with the present study the palaeoecological record is very short. Thus any possible climatic changes are most probably obscured by successional processes.

SYNTHESIS

The data from these sites indicate a slightly different environmental sequence for the hanging swamps on the Early Dune Land Unit compared to the Early Estuarine Land Unit.

Organic sediments on the Early Dune Unit began accumulating around 1680 B.P.. Periods of slope instability in the catchment were apparent as plant communities developed. In recent times the effects of magnetic aerosols have been noted in upper sediments.

Sediments began accumulating in the Early Estuarine Unit earlier, before 2410 B.P., probably because of their proximity to sea level. These saturated sediments were not as mobile as the cliff top dunes. Soon after, reworking of marine sands covered the deposit. Organic matter accumulation continued thereafter, accompanied by an increase in Aboriginal burning of the landscape. European settlement resulted in an increased sedimentation rate and increased turbidity of the swamp waters, a changed fire regime, and introduction of exotic plants. Magnetic aerosol particles were released into the air.

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